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Intensity-modulated radiosurgery with rapidarc for multiple brain metastases and comparison with static approach

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ABSTRACT

Rotational RapidArc (RA) and static intensity-modulated radiosurgery (IMRS) have been used for brain radiosurgery. This study compares the 2 techniques from beam delivery parameters and dosimetry aspects for multiple brain metastases. Twelve patients with 2–12 brain lesions treated with IMRS were replanned using RA. For each patient, an optimal 2-arc RA plan from several trials was chosen for comparison with IMRS. Homogeneity, conformity, and gradient indexes have been calculated. The mean dose to normal brain and maximal dose to other critical organs were evaluated. It was found that monitor unit (MU) reduction by RA is more pronounced for cases with larger number of brain lesions. The MU-ratio of RA and IMRS is reduced from 104% to 39% when lesions increase from 2 to 12. The dose homogeneities are comparable in both techniques and the conformity and gradient indexes and critical organ doses are higher in RA. Treatment time is greatly reduced by RA in intracranial radiosurgery, because RA uses fewer MUs, fewer beams, and fewer couch angles.

Introduction

Linac-based intracranial stereotactic radiosurgery (SRS) has been used to treat both malignant and benign brain lesions. The radiosurgical treatment has been traditionally delivered in terms of noncoplanar rotational arc beams with the aid of circular cones to provide beam collimation. The cone-based arc technique provides excellent dose coverage for small, solitary lesions. However, the circular cone–based SRS has the disadvantage that it requires long treatment times and it leaves large hot spots when treating large or irregular-sized lesion and for cases with multiple brain metastases. It is still used for the treatment of 1 or 2 small, solid lesions in our clinic and typically requires 50–60 min to set up and treat 1 lesion.[1–4]

The intensity-modulated radiation treatment (IMRT) using dynamic multileaf collimators (MLCs) has created new ways for beam collimation and modulation, and it provides optimal coverage for tumor volume and minimizing the dose to adjacent critical organs.[5–8] It has also allowed the practitioners to establish IMRT-based radiosurgery (IMRS) for treating large or irregular lesions. IMRS has been also implemented for the treatment of multiple intracranial metastases in our clinic since 2006. In our approach, a single isocenter is used for simultaneously treating multiple brain lesions in a single fraction. The IMRS plan normally uses 8–11 noncoplanar static IMRT fields to deliver radiation dose, and the whole treatment can be finished within 45–60 min, including patient setup, independent of how many lesions are included in the treatment.[9–11]

Recent innovation further incorporates the intensity-modulated technology with the rotational beam delivery. RapidArc (RA) radiotherapy (Varian Medical Systems, Palo Alto, CA) is a volumetric arc therapy that delivers modulated beams during gantry rotation with simultaneous adjustment of gantry rotation speed, MLC field aperture, and dose delivery rate.[12–15] It has the capability of using fewer monitor units (MUs) and faster dose delivery than the regular IMRT treatment. RA technique has been used in our clinic since 2009 to treat various tumor sites, and has also been implemented for the intracranial radiosurgery of brain metastases.

The goal of this study was to evaluate the RA technique in the treatment of intracranial metastases and to compare results with the IMRS treatments. The issues discussed in this study regard not only the beam characteristics but also the dosimetry features, especially when they are compared with the static IMRS technique. Both the pros and cons of RA technique are presented.

Methods and materials

Twelve patients with multiple brain lesions treated with IMRS during 2007–2009 were selected for comparison and replanned using the RapidArc technique. Computed tomography (CT) simulation was performed with 512 × 512 pixels at 1.25-mm slice spacing. All patients have undergone T1-weighted magnetic resonance (MR) scan with

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contrast, following scanning protocol of 26-cm field of view, 512 × 512 pixels, and 1–1.5-mm slice spacing. Image fusion was performed based on anatomy-matching in terms of gray scales. The clinical target volume (CTV) was delineated individually on the axial MR slices by a neurosurgeon after the fusion was confirmed. In this group, the prescribed dose was the same for different lesions for each patient. A single structure (called CTV) has been used as the composite of all the lesions. The average lesion number in the group was 7 (range, 2–12) and the average CTV volume was 6.3 cc (range, 1.2–14.3). The planning target volume (PTV) was generated from CTV by a geometrical expansion of 2 mm to account for setup and other uncertainties, based on retrospective analyses of our clinical records.[16]

The critical organs, including normal brain, brainstem, chiasm, right and left optical nerves, and right and left eyes, have all been contoured. The normal brain is defined as the total brain volume excluding the PTV and the brainstem. Expansions of brainstem and chiasm by 5 mm and 3 mm, respectively, have been used to better achieve the goals in the optimization. The expansion was not used for eyes in IMRS planning because they have been mostly excluded from the treatment fields.

The prescribed dose of SRS of brain metastases for patients treated in the clinic depends on the lesion size and the proximity to critical organs. In this group, the prescribed dose has ranged from 18 –20 Gy in a single fraction.

IMRS planning

The IMRS plans have been produced using the Eclipse planning system V 8.2 (Varian Medical Systems) and delivered on a Varian Trilogy linear accelerator. The Trilogy was equipped with a Millennium MLC, which had 120 leaves, 5-mm leaf width within the central 20 cm of the field, and 10-mm leaf width in the outer 20 cm. The SRS-6X mode of 1000 MU/min dose rate with sliding window technique has been used for 11 patients in the group, whereas 6X mode of 600 MU/min dose rate has been used for the remaining patient. The SRS-6X had a field size limit of 15 × 15 cm. According to experience, this field size was enough to cover multiple brain lesions with the properly selected beam gantry angles and collimator rotations. The IMRS plan typically used a single isocenter and 9 (range, 8 –11) noncoplanar IMRT fields. The isocenter was most likely located in the center of the brain, not necessarily within any particular lesion. Each of the beams was carefully oriented to provide optimal PTV coverage and critical organ sparing, and they formed, as a whole, a solid angle as large as possible. The objectives of PTV dose coverage and the sparing of critical organs and their expansions have both been used in the optimization.

RapidArc planning

RA plans have been generated using the volumetric dose optimization method in the Eclipse planning system V8.6 using Varian 23IX and 6X mode of 600 MU/min dose rate based on clinical availability. Varian 23IX was equipped with the same Millennium MLC as the Trilogy. The field size of the volumetric arc beam in this group used x-jaw (x1+x2) no larger than 15 cm, and y-jaw (y1+y2) no larger than 18 cm. We used 2-arc and 3-arc plans for the treatment of brain lesions in our clinic. The plans with 2 coplanar arcs were compared with the 3 arcs—an additional partial vertical arc was added to the 2 coplanar arcs. Based on our clinical practice and comparison results on treatment time, dose conformity, and critical organ dose (see *2-arcs* vs. *multiple arcs* in Results), the 2-coplanar arc approach has been chosen for all patients in the study. The isocenter of RA coincided with IMRS isocenter in most of the cases, because it was located near the center of the brain.

The structures of the right and left eye expansion of 2 mm have been added and used in arc optimization as an attempt to further decrease the eye dose in RA (see Results and Discussion sections). All RA plans have followed the same systematic strategy in arc optimization regarding objectives, weights, and MU limit. For each patient, several RA plans were generated with differences in arc lengths, avoidance sectors, or emphases in MU limits and objectives of critical organ dose. The plan with lower MUs and higher conformity has been chosen as the final plan for comparison with IMRS.

The same IMRS isocenter is used in the RapidArc plan for each patient in this study, because the isocenter is located at approximately the center of the brain. The feature of *Adjust Arc Field Geometry* in arc optimization has not been routinely used in our practice, because it is often found that the isocenter repositioning and the couch angle adjustment may not better meet the needs of patient treatment. Instead, the feature of *MLC segment animation* is used to preview the lesion coverage and possible critical organ sparing through the beam rotation before the optimization. This kind of visual inspection allows us to better select the jaw size, collimator angle, and gantry rotation length. The collimator angle is usually set at 45° but may vary with patient, ranging from 30 – 60° (for the first arc); the gantry rotation length is usually 358° with variation of 280 –359.8°; and the asymmetric jaws are often used.

Dose normalization

The dose normalization in the original IMRS plans was based on the outcome of individual dose volume histogram (DVH). For comparison, all the IMRS plans in the study were renormalized such that 100% of the prescribed dose (PD) covered 98% of the PTV volume. This renormalization did not change the isodose distribution and only caused minimal adjustment of MUs in each IMRS plan. The differences in MUs of all the IMRS plans caused by renormalization ranged from 0 –159 MU (0 –1.9%). The median and mean percentage differences before and after renormalization are 0.0% and 0.2%, respectively. For consistency, the dose normalization was chosen in such a way that 100% of PD covers 98% of PTV volume in all of the RA plans.

Dosimetric indexes for target coverage

For plan evaluation, the following dosimetric parameters and indexes were used in the study, following RTOG protocol and other related literatures.[17–19] The maximum PTV dose (MD) has been calculated for both IMRS and RA plans for all patients. The homogeneity index (HI) is defined as the ratio of MD to PD, which is a measure of the dose homogeneity within the PTV volume.

$$\text{Homogeneity index:}\ HI = MD/PD. \tag{1}$$

The volume enclosed by 100% of the prescribed dose has been calculated in all plans and denoted as V_{100}. The conformity index (CI) is defined as the ratio of the volume of 100% dose cloud V_{100} to the PTV volume,

$$\text{Conformity index:}\ CI = V_{100}/PTV. \tag{2}$$

To evaluate dose gradient, the volume enclosed by the 50% dose cloud in each plan was also calculated (V_{50}). Radii of the equivalent spheres of V_{100} and V_{50} can be derived. The gradient index is defined as the radial difference of the 2 equivalent spheres of V_{50} and V_{100}.

$$\text{Gradient index:}\ GI = R_{50} - R_{100}. \tag{3}$$

As often cited in the literatures, Paddick conformity index (PCI) may be a better representation of the dose conformity.[18,19]

Table 1
Tumor, prescription, number of lesions, and beam parameters in IMRS and RA plans

					9-beam IMRS		2-arc RapidArc		
Patient number	CTV (cm³)	PTV (cm³)	PD (Gy)	No. of lesions	Couch angles	Total MU	Couch angles	Total MU	MU ratio (RA/IMRS)
1	12.1	21.1	20	2	6	3641	1	3787	104%
2	3.4	8.9	20	4	7	4369	1	4025	92%
3	1.2	3.8	20	4	9	6656	1	5233	79%
4	3.1	5.7	20	5	7	6345	1	4067	64%
5	5.3	13.3	20	6	7	5597	1	4432	79%
6	1.6	5.7	20	7	8	5852	1	4325	74%
7	3.1	9.9	20	8	8	6604	1	4422	67%
8	14.3	28.7	20	8	8	8196	1	4511	55%
9	8.0	20.7	20	8	8	7840	1	3915	50%
10	9.7	22.0	20	9	7	8565	1	3884	45%
11	6.0	14.4	18	9	8	9562	1	3517	37%
12	7.5	20.3	20	12	6	9828	1	3851	39%
Avg.	6.3	14.5	19.8	7	7	6921	1	4167	65%
SD	±4.2	±8.0	±0.6	±3	±1	±1937	±0	±453	±21%

PD; Couch angles in RA couch are all at 0.